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FOREST CANOPY STRUCTURE DERIVED FROM SPATIAL AND SPECTRAL HIGH RESOLUTION REMOTE SEINSING DATA

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ABSTRACT

Forest canopy structure can be described by a variety of biophysical parameters, for example leaf area index (LAI) and fractional cover (fcover). These parameters are derived currently from remotely sensed data only with limited accuracy. The retrieval of biophysical parameters is often conducted by empirical models based on vegetation indices (VI) exploiting the spectral information but ignoring the spatial dimension contained in remote sensing data. However, texture information provided by high spatial resolution data can be potentially used as additional information related to the forest structure and might improve the models for the retrieval of biophysical parameters. The aim of this research is to evaluate several methods to combine spectral and textural information to derive the best retrieval method of LAI and fcover from spectral and high spatial resolution remote sensing data in a coniferous forest in the Swiss National Park.

Spectral data as well as spatial data contain information, which can be correlated with the field measurements of biophysical forest parameters. The relationship between spectral data and the field measurements proved to be slightly better than between spatial data and field parameter.

INTRODUCTION

As a consequence of the increasing climate change, interests in the boreal coniferous forests and the associated carbon sinks strengthened very strongly in the last years. Boreal forests cover approximately 21 % of the forest land surface of the Earth and account for 13% of the carbon stored in the biomass (1). The characterisation of the forest structure is the basis for an exact estimation of carbon fixed in the boreal zone by biophysical parameters as Leaf Area Index (LAI) or fractional cover (fcover). There is a direct relationship between these parameters and the exchange of energy, CO_2 and steam between plant canopies and the atmosphere. For example, physiological processes such as photosynthesis, transpiration and evapotranspiration are a function of LAI (2). Accordingly, estimation of biophysical parameters from remote sensing instruments is of wide interest and significance.

There are different approaches to derive biophysical parameters from remote sensing data. Empirical studies involving spectral reflectance values are the frequently and successfully applied techniques in the estimation of LAI (3). Spectral indices are semi-empirical, relatively simple, and offer regression-based relationships between remotely sensed radiance indices and biophysical parameters (4). Vegetations indices such as the normalized vegetation difference indices (NDVI) may be viewed as a surrogate for scene vegetations content (5). A difficulty in estimation of biophysical parameters from vegetation indices is for example the asymptotic relationship between NDVI and LAI which results in a limited variation in NDVI values for LAI values greater than approximately 4.5 in forest stands (6). The vegetation index values are of a limited range as a consequence of being derived from of a passive remote sensing platform, which may only assess the horizontal expression of a stand.

The dynamic nature of forest conditions limits the ability to predict from a single information source, such as NDVI. As the NDVI is derived from image spectral values, any forest structural variability will be related to the computed NDVI values. For example, factors such as differences in crown closure, shadows or stand density may result in markedly different stand structures, yet will be still represented by the same NDVI (4). For example internal stand shade conditions, such as mutual shadowing, will actually result in a decrease of NDVI as LAI increases. However, internal stand shade conditions may be detected in measures of image texture computed on imagery of high spatial resolution. Texture may be used to provide structural information when the relationship between spectral information and LAI diminishes (4). Texture, in the context of digital image processing, is the spatial variability of image tones which describes the relationship between elements of surface cover. Therefore, it follows that texture contains structural information, as the variation of image tones is related to changes in the spatial distribution in of forest vegetation (4).

The objective of this study is to understand how the spectral and textural information relates to biophysical parameters and subsequently how the combination of these two information dimensions might improve the description of the biophysical parameter. The approach is also based on a number of experiments published in the literature (4, 5, 7, 8).

FIELD SITE AND DATA SET

The study area for the acquisition of the field data is located in the Eastern Ofenpass valley which is part of the Swiss National Park (SNP). The Ofenpass represents an inner-alpine valley at an average altitude of about 1900 m a.s.l, with an annual precipitation of 900–1100 mm.

The south-facing Ofenpass forests, the location of the field measurements, are largely dominated by mountain pine (Pinus montana ssp. arborea) and some stone pine (Pinus cembra L.), a second tree specie that is of interest for natural succession (9-11). These forest stands can be classified as woodland associations of Erico–Pinetum mugo (11). The understory is characterized by low and dense vegetation composed mainly of various Ericaceae and Sesleria species.

Sampling scheme

Four core test sites (labeled LWF1, LWF2, STA1, and STA2) and several additional distributed point samples describe the canopy and the spectral characteristics of the study area. The core test sites were selected following a stratified sampling scheme to cover different canopy densities within a stand of P. montana ssp. arborea (Figure 1). They were set up accordingly to the elementary sampling units of the VALERI scheme (12). Each site was defined by nine sampling points, evenly spaced in a grid spacing of 10 m, covering a square area of 20*20 m. The coordinates of the sampling points were georeferenced by nondifferential GPS receivers. Measurements of the biophysical variables describing the canopy were performed at all sampling points between the 7th and the 15th of August 2002.

Canopy structure

Canopy structure was described using two different methods, well known in literature and adapted to heterogeneous canopies (13, 14). Measurements were carried out using two canopy analyzer LAI2000 (15) and hemispherical photographs to provide canopy structure variables (16) separately for the crown and understory layer. The LAI2000 was used to estimate two canopy variables the effective leaf area index (LAI) and fractional cover. The LAI2000 provided an effective plant area index representing green foliage and woody area rather than just the green leaf area per unit ground surface area. The clumping effects at the shoot and crown level, typical for coniferous foliage, were corrected following an approach proposed by Chen et al. (1997b). Values for the clumping index of mature Pinus banksiana canopies, a tree specie similar to the investigated species, were applied (13). The uncertainties associated with the LAI and the fractional cover provided by the LAI2000 were assessed based on the standard deviation of five reference measurements taken at each measurement point. Observed LAI values ranged between 1.78 and 3.99 (Table 1).

Hemispherical photographs taken in parallel with the LAI2000 measurements allowed the separation of the canopy into its constituents foliage and wood fractions, i.e., needles, trunk and branches (17, 18). The algorithm allows to classify the photograph into its image elements (19). Subsequently, the classification technique allowed woody parts and green foliage, and their respective gap fractions, to be distinguished based on their respective colors. Observed LAI values ranged between 1.59 and 3.65 (Table 2).

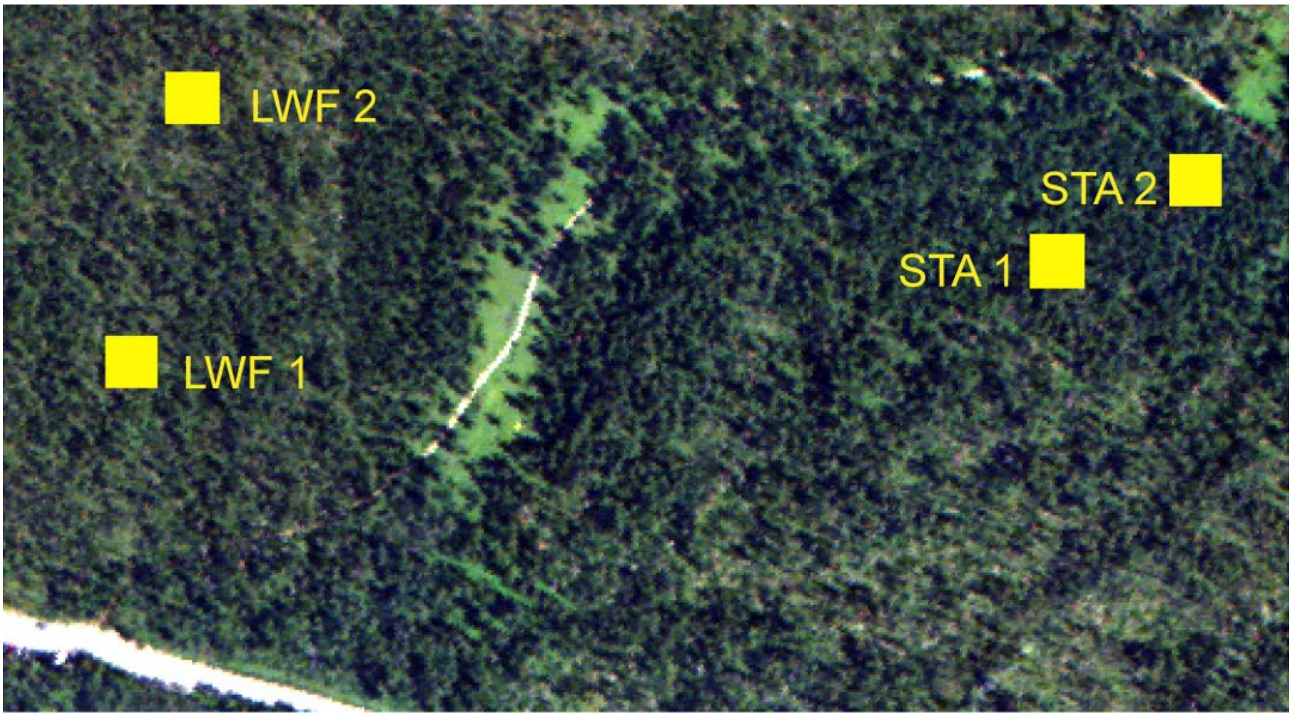

Figure 1: Airborne imaging spectrometer data over the four test sites. The image composite represents geocoded and atmospherically corrected data of the spectrometer ROSIS in spatial resolution of 1 m resolving the heterogeneity of the observed forest

Table 1: Statistical values of the individual test areas measured by LAI-2000 (average and standard deviation of the 9 subplots comprised in each plot)

		LWF 1	LWF 2	STA 1	STA 2	TOTAL
LAI	mean	2.18	1.78	3.89	3.99	2.96
	STDV	0.53	0.58	1.04	0.54	1.21
FCover	mean	0.38	0.34	0.63	0.69	0.51
	STDV	0.15	0.22	0.17	0.2	0.23

Table 2: Statistical values of the individual test areas measured by hemispherical photos (average and standard deviation of the 9 subplots comprised in each plot)

		LWF 1	LWF 2	STA 1	STA 2	TOTAL
LAI	mean	1.59	1.84	3.56	3.65	2.66
	STDV	0.08	0.304	0.294	0.48	1.07
FCover	mean	0.191	0.080	0.461	0.308	0.26
	STDV	0.25	0.08	0.32	0.27	0.27

Imaging data

The ROSIS imaging spectrometer data were aquired on the 14th of August 2002 in parallel to the ground measurements. The local illumination and observation conditions were summarized by a solar zenith angle of 45.3°, a solar azimuth angle of 122.9°, and the flight heading of 293°.

ROSIS covered a spectral range from visible to the near infrared with 115 bands. The image was geoatmospherically processed with the modules PARGE and ATCOR4 to obtain geocoded top-of-canopy reflectances (20-22).

HRSC data were acquired on the 11th July, 2003. HRSC is a pushbroom camera with 9 CCD-arrays and 5 different spectral bands. The HRSC-scene shows a spatial resolution of 0.15 m. The radiometric correction includes a flatfield- and a dark current correction. No absolute calibration nor an atmospheric correction has been performed for the HRSC camera data.

RELATIONSHIPS OF BIOPHYSICAL PARAMETERS TO SPECTRAL AND SPATIAL DATA

Spectral data as well as spatial data were evaluated for their performance to retrieve biophysical forest parameters, LAI and fcover, on two levels of spatial scale. The Plot level represented the average from 9 single measurements in each test site. The Subplot level considered the 9 single values in each test site. For the spectral as well as the spatial information several approaches were tested and the most promising results are presented in the following.

Spectral data

Plot level as well as Subplot level show a positive relationship between NDVI and the LAI-2000 measured Leaf Area Index (Figure 2). At plot level the sample is too small for a qualitative statement but the correlation is clearly evident. At subplot level the NDVI – LAI relationship shows a R^2 with low significance. For example R^2 = 0.36 with a 9 m window size (Figure 2).

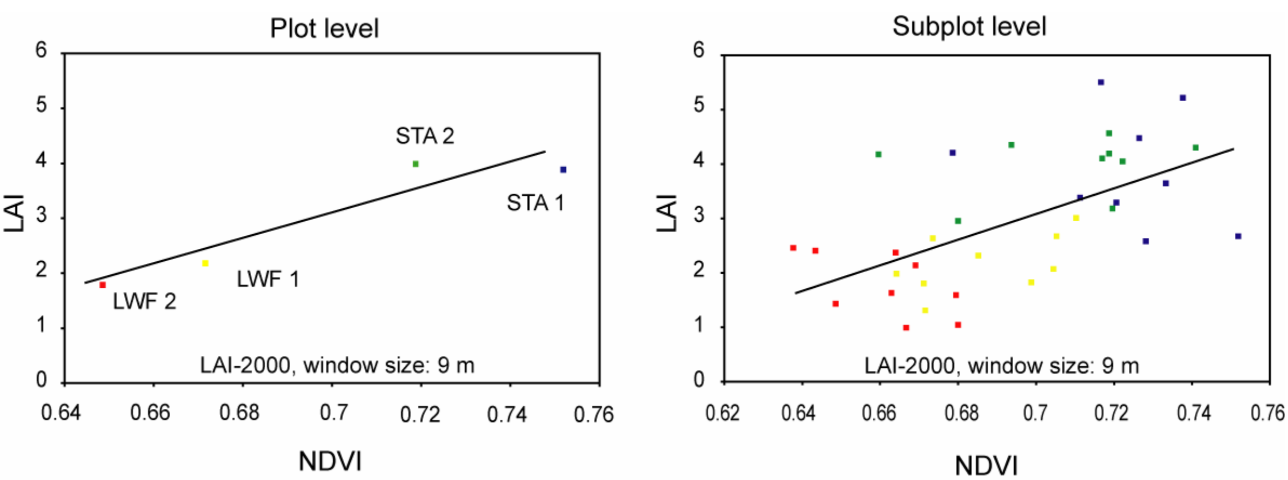

Figure 2: Positive relationship between NDVI and the field measured LAI

In the comparison of the field measuring methods no significant difference is visible. Both methods show the same curve progression over the different window sizes (Figure 3).

At Plot level a significant relationship between LAI and NDVI above a window size of 3 m is visible. This value is equivalent to the average crown diameter. In smaller window sizes the heterogeneity between shadows, understory and crowns is too large for a sensible detection of the differences in LAI. Above a window size of 3 m the single scene components are averaged and the canopy instead of the mosaic of shadows, understory and crowns is detected.

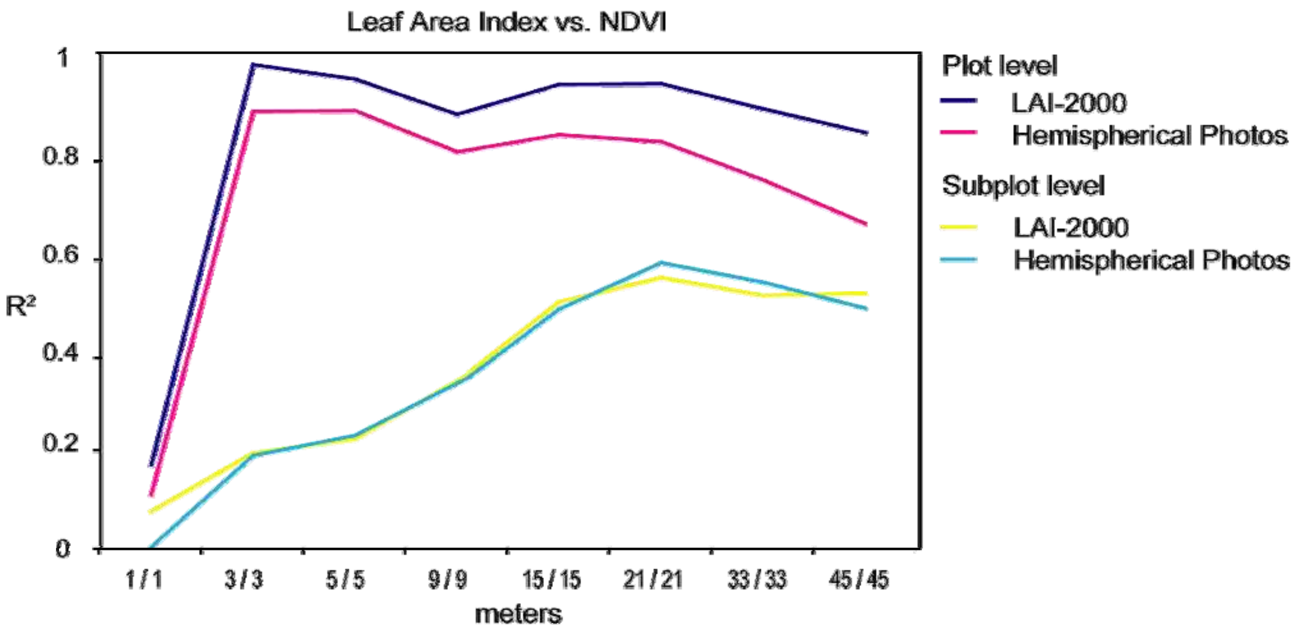

Figure 3: R^2 of the relationship LAI – NDVI for different window sizes and field measurement instruments

At subplot level an increasing R^2 with increasing window size is observed. However, on the one hand the measurements for small window sizes are not representative (1-3 meters window size), since the hemispherical photos cover a larger area depending on the canopy height. On the other hand, problems with the independency of the calculated vegetation indices for the single subplots occur above a window size of 15 meters. The individual windows begin to overlap themselves and can't be seen anymore as an independent observation. As a consequence, the R^2 of the relation between field measurements and vegetation indices improves automatically.

Also uncertainties related to the field measurements of 20% and geo localization errors add to the difficulties to establish a stable relationship based on single field observations.

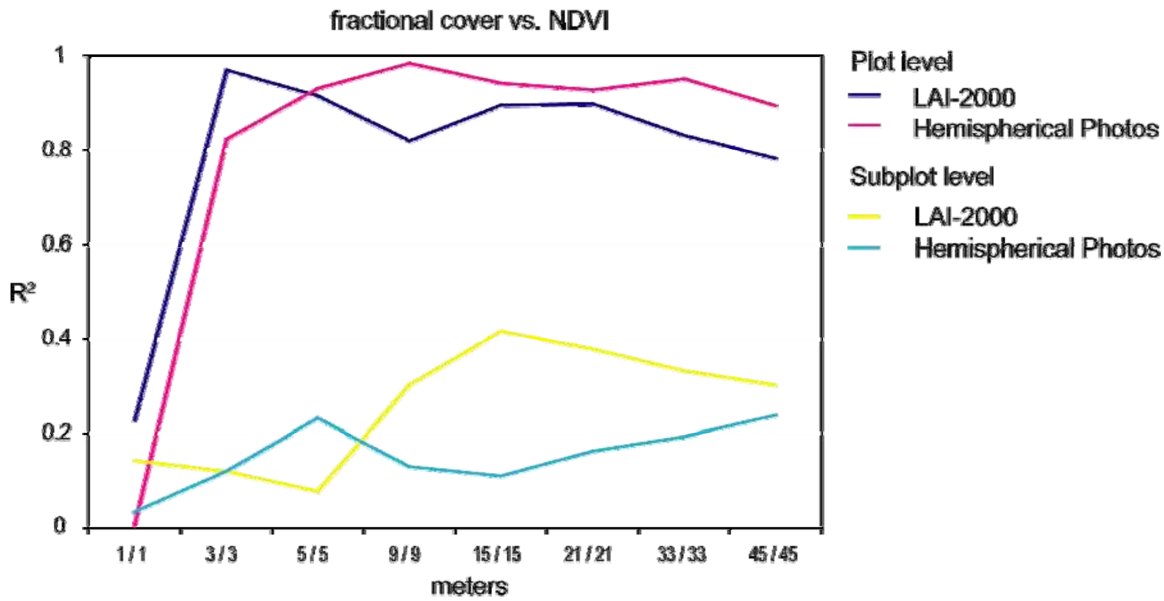

Figure 4: R^2 of the relationship fcover – NDVI for different window sizes and field measurement instruments

The results for the retrieval of fractional cover present a different picture (Figure 4). In contrast to the Leaf area index single hemispherical photos seem not suitable to measure fcover in the field. In the small zenith angle (10°) that is used for the computation of fcover from hemispherical photos, often no vegetation is observed. Therefore a higher number of observations are necessary to sample representatively the canopy closure.

Compared with other vegetation indices, for example the soilline-based perpendicular vegetation index (PVI), NDVI seems to be very stable over all window sizes (Figure 5). In contrast to the NDVI the R^2 of the relationship between PVI and LAI/fcover varies very strongly.

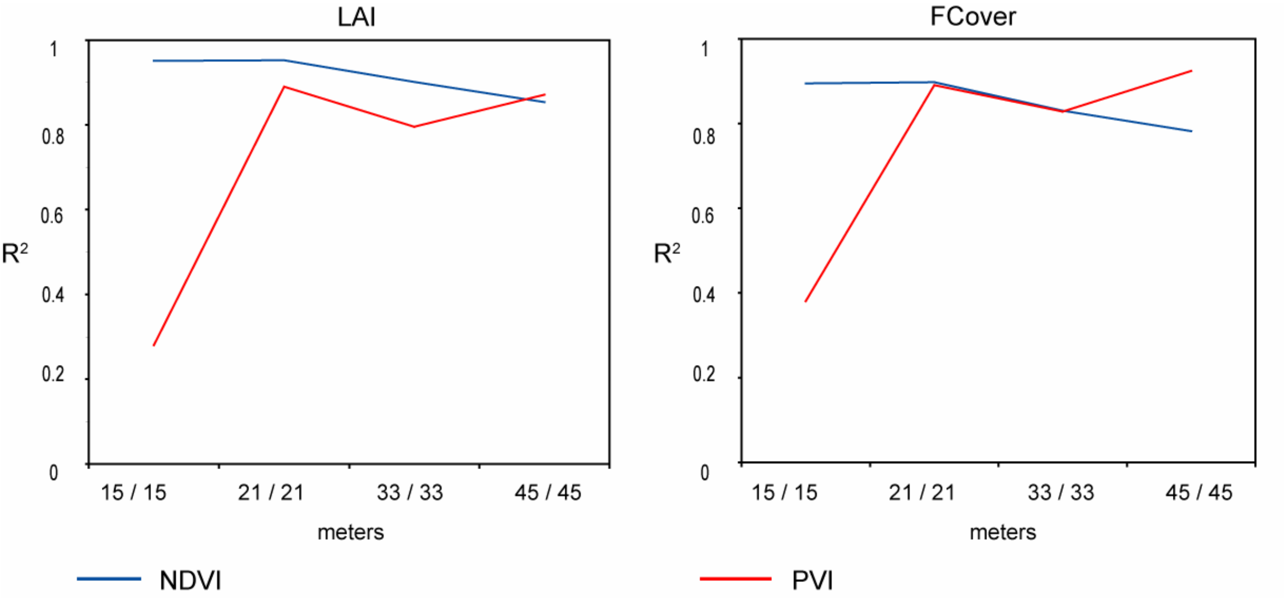

Figure 5: R^2 of the relationship between different vegetation indices and the biophysical parameters (plot level, LAI-2000)

Spatial data

For the exploitation of the spatial information two texture measures have been employed: the dissimilarity and the variance with in varying window sizes. A negative relationship between dissimilarity and field measured LAI (LAI-2000) at plot level as well as at subplot level could be observed (Figure 6). This demonstrates the feasibility of the biophysical parameter retrieval based on spatial information content alone. With increasing LAI the heterogeneity caused by differences between shadow, understory and crown decreases, which results in a reduced dissimilarity.

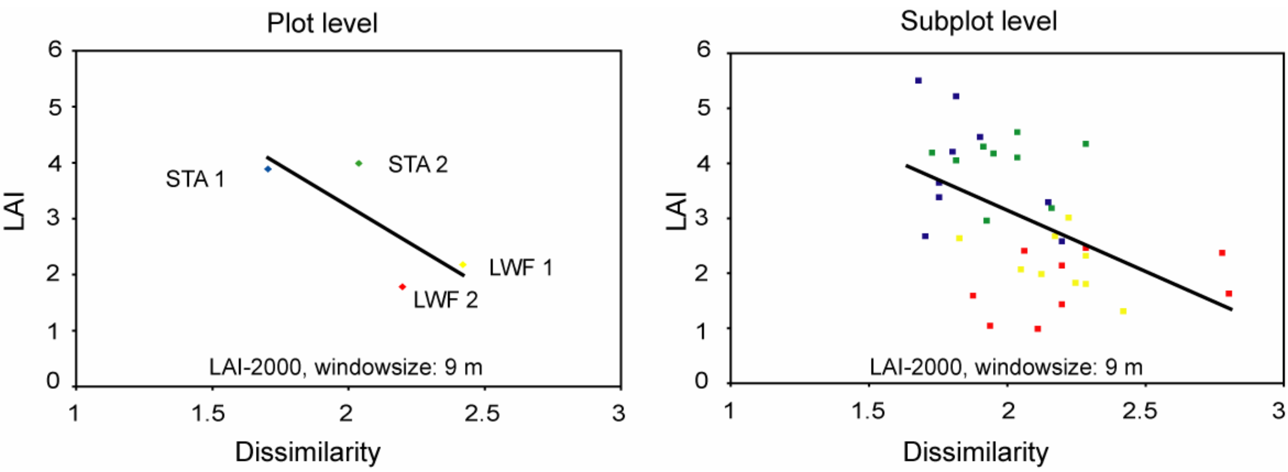

Figure 6: Negative relationship between dissimilarity and the field measured LAI (hemispherical photos)

Variance as well as dissimilarity show a strong relationship with the biophysical parameters at window sizes between 15 and 45 meters. Dissimilarity seems to contain more Information than dissimilarity (Figure 7).

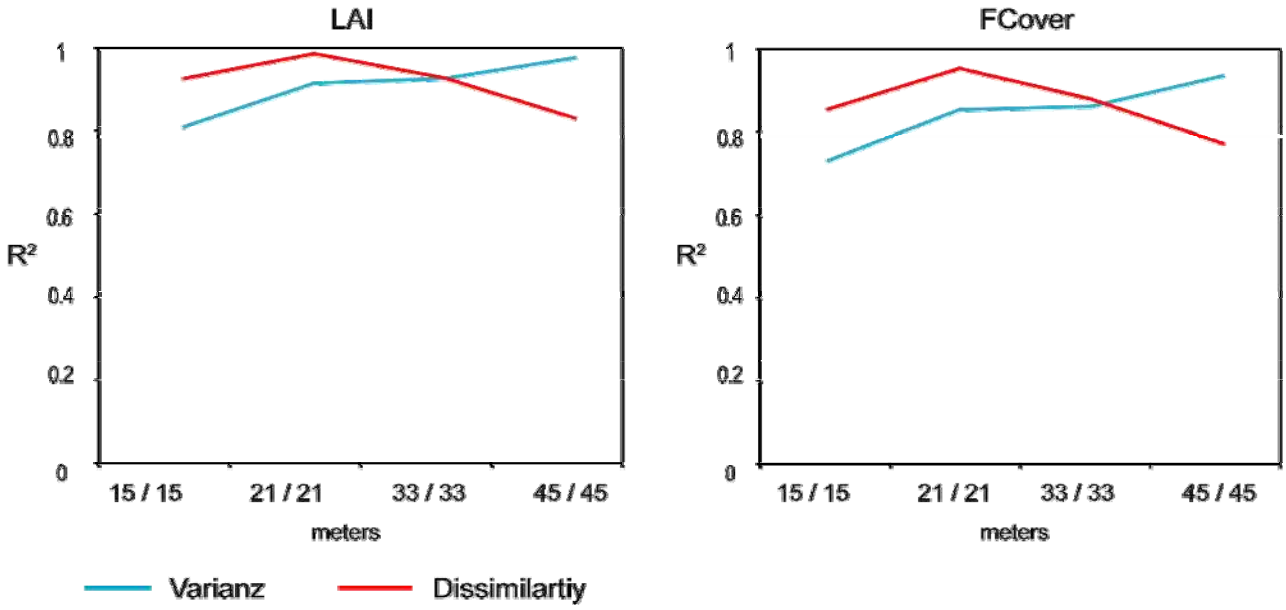

Figure 7: R^2 of the relationship between different texture parameters and the biophysical parameters with varying window sizes (plot level, LAI-2000)

Spectral and spatial data

The relationship between the combined VI-texture data versus LAI was tested by performing multiple linear regressions, with LAI as dependent variables and VI/texture as independent parameters.

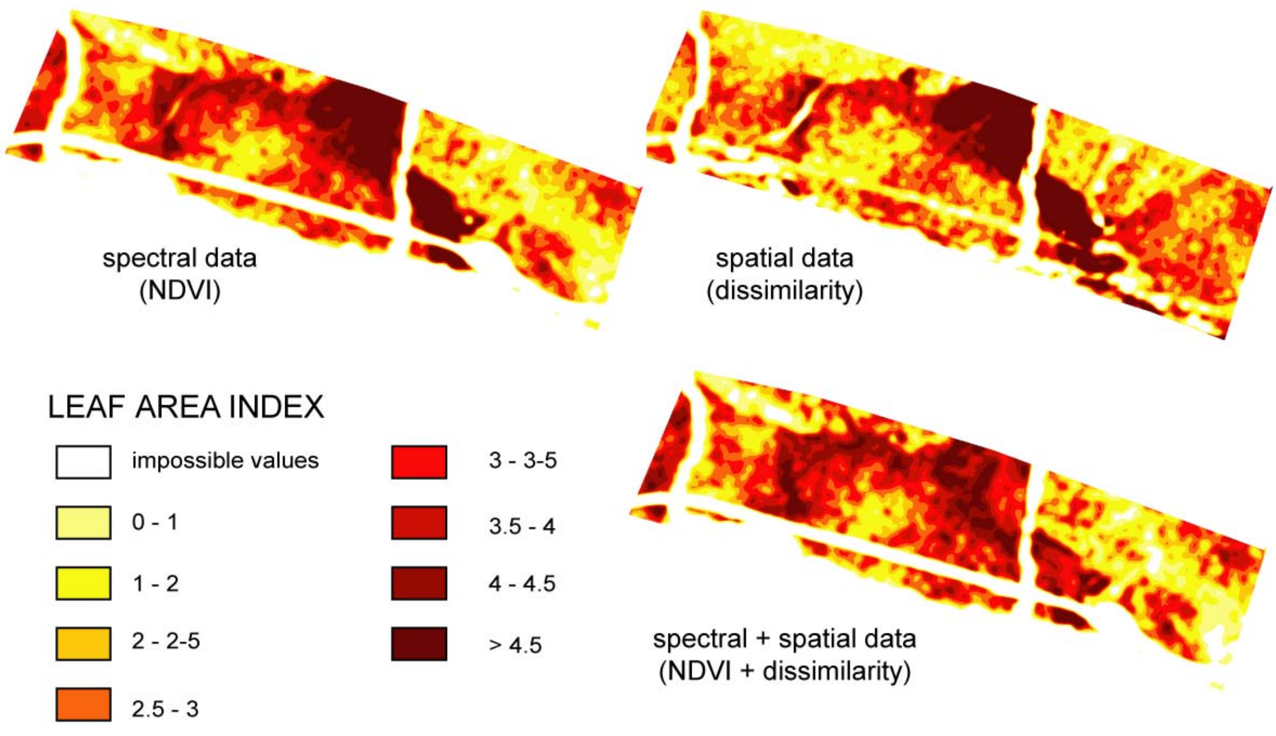

Figure 8: Maps of LAI retrieved from spectral, spatial and spectral & spatial data

Maps of LAI retrieved from spectral data as well as spatial data contain information which can be correlated with the field data and both can be used to map leaf area index and fractional cover. A visual inspection of the maps suggests that the spectral information content has more influence on the combined method than spatial data (Figure 8).

High values of LAI (>4.5) are found on the alpine meadow Stabelchod. However, it has to be mentioned that the empirical methods employed here are only valid for the vegetation type they were calibrated for. Consequently, results over vegetation types other than coniferous forest, such as a meadow, have to be handled with care. Many pixels along brooks or streets show negative LAI-Values (white on the map).

For other methods employed on the same study area, for example radiative transfer modelling (23) or LIDAR-based methods (24, 25) the same spatial patterns for the retrieved biophysical parameters were found. These comparable studies confirm the plausibility of the above-presented results.

CONCLUSIONS

The presented results suggest that spectral data as well as spatial data contain information, which can be correlated with the field measurements of biophysical forest parameters. The relationship between spectral data and the field measurements proved to be slightly better than between spatial data and field parameter.

A study to determine the optimal spatial resolution for the retrieval of biophysical parameters (LAI and fcover) showed the need of a spatial resolution on the canopy scale. A spatial resolution above the average crown diameter is consequently recommended for the development of empirical relationships between passive remote sensing data and state of the art field measurements. For higher resolution the influence of shadows, understory and crowns leads to a very high heterogeneity, which does not allow for the establishment of stable relationships. Nevertheless, high resolution remote sensing data is needed for the computation of the texture information.

A slight increase of the R^2 suggests that the integration of image texture can improve slightly, but spectral data seems more suitable for the retrieval of biophysical parameters than spatial data.

References

1. Danson, F. M., *Temperate Forest Rescource Assessment by Remote Sensing*, in *Encyclopedia of Analytical Chemistry*, R.A. Meyers, Editor. 2000, John Wiley & Sons Ltd: Chichester. p. 8814-8827.
2. Pierce, L. L. and Running, S. W., *Rapid Estimation of Coniferous Forest Leaf-Area Index Using a Portable Integrating Radiometer.* Ecology, 1988. 69(6): pp. 1762-1767.
3. Nemani, R., Pierce, L., Running, S., and Band, L., *Forest Ecosystem Processes at the Watershed Scale - Sensitivity to Remotely-Sensed Leaf-Area Index Estimates.* International Journal of Remote Sensing, 1993. 14(13): pp. 2519-2534.
4. Wulder, M. A., Le Drew E. F., Franklin S. E., and Lavigne M. B.*, Aerial image texture information in the estimation of northern deciduous and mixed wood forest leaf area index (LAI).* Remote Sensing of Environment, 1998. 64: pp. 64-76.
5. Wulder M.A., Franklin S. E., and Lavigne M.B., *High spatial resolution optical image texture for improved estimation of forest stand leaf area index.* Canadian Journal of Remote Sensing, 1996. 22(4): pp. 441-449.
6. Chen, J. M., *Optically-Based Methods for Measuring Seasonal Variation of Leaf Area Index in Boreal Conifer Stands.* Agricultural and Forest Meteorology, 1996. 80(2-4): pp. 135-163.
7. Weiss, M., Troufleau, D., Baret, F., Chauki, H., Prevot, L., Olioso, A., Bruguier, N., and Brisson, N., *Coupling Canopy Functioning and Radiative Transfer Models for Remote Sensing Data Assimilation.* Agricultural and Forest Meteorology, 2001. 108(2): pp. 113-128.
8. Colombo, R., Bellingeri, D., Fasolini, D., and Marino, C. M., *Retrieval of Leaf Area Index in Different Vegetation Types Using High Resolution Satellite Data.* Remote Sensing of Environment, 2003. 86(1): pp. 120-131.

9. Lauber, K. and Wagner, G., *Flora Helvetica. Flora Der Schweiz*. 1996, Bern, Stuttgart, Wien: Paul Haupt Verlag. pp. 1613.
10. Zoller, H., *Vegetationskarte Des Schweizerischen Nationalparks Und Seiner Umgebung*. 1992, Hallwag AG: Bern.
11. Zoller, H., *Vegetationskarte Des Schweizerischen Nationalparks. Erläuterungen*, ed. S.A.o.S. SAS. Vol. Nr.85. 1995: National Park Forschung. pp. 108.
12. Baret, F., *Valeri: A Network of Sites and a Methodology for the Validation of Medium Spatial Resolution Land Satellite Products.* Remote Sensing of Environment, 2005. submitted.
13. Chen, J. M., Blanken, P. D., Blank, T. A., Guilbeault, M., and Chen, S., *Radiation Regime and Canopy Architecture in a Boreal Aspen Forest.* Agricultural and Forest Meteorology, 1997. 86(1-2): pp. 107-125.
14. Smolander, H. and Stenberg, P., *Response of Lai-2000 Estimates to Changes in Plant Surface Area Index in a Scots Pine Stand.* Tree Physiology, 1996. 16(3): pp. 345-349.
15. LI-COR, *Lai-2000 Plant Canopy Analyzer – Operating Manual*. 1992, Lincoln, Nebraska: LI-COR, Inc. 1-1 - 10-1.
16. EYE-CAN, *Eye-Can 1.0: A Software to Process Hemispherical Images for Vegetation Biophysical Characteristic Estimation*. 2003, NOVELTIS, INRA: Ramonville.
17. Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., and Baret, F., *Review of Methods for in Situ Leaf Area Index Determination - Part I. Theories, Sensors and Hemispherical Photography.* Agricultural and Forest Meteorology, 2004. 121(1-2): pp. 19-35.
18. Weiss, M., Baret, F., Smith, G. J., Jonckheere, I., and Coppin, P., *Review of Methods for in Situ Leaf Area Index (Lai) Determination Part Ii. Estimation of Lai, Errors and Sampling.* Agricultural and Forest Meteorology, 2004. 121(1-2): pp. 37-53.
19. Finney, M. A., *Farsite: Fire Area Simulation - Model Development and Evaluation.* USDA Forest Service, Rocky Mountain Research Station, 1998. Research Paper RMRS-4.
20. Richter, R. and Schläpfer, D., *Geo-Atmospheric Processing of Airborne Imaging Spectrometry Data. Part 2: Atmospheric/Topographic Correction.* International Journal of Remote Sensing, 2002. 23(13): pp. 2631-2649.
21. Schläpfer, D., Koetz, B., and Gruber, S. *The Influence of Dem Characteristics on Preprocessing of Dais/Rosis Data in High Altitude Alpine Terrain*. in *3rd EARSEL Workshop on Imaging Spectroscopy*. 2003. Oberpfaffenhofen.
22. Schläpfer, D. and Richter, R., *Geo-Atmospheric Processing of Airborne Imaging Spectrometry Data. Part 1: Parametric Orthorectification.* International Journal of Remote Sensing, 2002. 23(13): pp. 2609-2630.
23. Kötz, B., Schaepman, M., Morsdorf, F., Bowyer, P., Itten, K., and Allgower, B., *Radiative Transfer Modeling within a Heterogeneous Canopy for Estimation of Forest Fire Fuel Properties.* Remote Sensing of Environment, 2004. 92(3): pp. 332-344.
24. Morsdorf, F., Meier, E., Kötz, B., Itten, K. I., Dobbertin, M., and Allgower, B., *Lidar-Based Geometric Reconstruction of Boreal Type Forest Stands at Single Tree Level for Forest and Wildland Fire Management.* Remote Sensing of Environment, 2004. 92(3): pp. 353-362.
25. Morsdorf, F., Koetz, B., Meier, E., Itten, K., and Allgöwer, B., *Estimation of Lai and Fractional Cover from Small Footprint Laser Scanning Data.* Remote Sensing of Environment, submitted.